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MORPHOLOGICAL RELATIONSHIPS IN THE ONTOGENY OF THE CULTIVATED CUCUMBER, *CUCUMIS SATIVUS L.*[1]

ARTHUR E. HUTCHINS

INTRODUCTION

The developmental processes that culminate in the production of mature characters in plants have received little attention. Wilson (1), as a statement of the central problem of heredity, propounds this question, "How do the adult characteristics lie latent in the egg and how do they become patent as development proceeds?" The latter feature of this problem, "How do they become patent as development proceeds," appears to have been neglected. While it is probable that a mature character is the end result of a differentiation occurring at the beginning of development of the fertilized egg, very little information is available as to how this differentiation is expressed in the early stages of growth and in the mature characters of the plant. Morphological studies may be used as a tool to throw some light on this phase of heredity. Such a study, involving several characters of the cultivated cucumber, is presented in this paper.[2]

STATEMENT OF THE PROBLEM

During the course of inbreeding studies on varieties of *Cucumis sativus L.* (2), it was observed that certain differences in the characters of some strains and varieties appeared to result from a general growth habit or behavior. These differences seemed to be due either to the relative growth of the width to the length of the various organs or merely to a variation in their longitudinal growth. For example, a certain shape appeared to be characteristic of the various organs of a cucumber variety; that is, if the fruit was long and slender, the unfertilized ovaries, cotyledons, leaves, internodes, seeds, and certain other organs were also long and slender. This investigation was therefore undertaken as a matter of scientific interest, with the possibility that it might prove of practical value as well. The purpose was to determine,

[1] A thesis submitted to the faculty of the Graduate School of the University of Minnesota in partial fulfillment of the requirements for the degree of Doctor of Philosophy.

[2] In the development of this study and in the analysis of the results obtained, the writer is deeply indebted to Dr. F. A. Krantz for his valuable aid and criticism. Sincere thanks are also due the late Dr. J. Arthur Harris for his suggestions and guidance in the use of biometrical methods and for his apt criticisms of part of the data. Many constructive criticisms have also been received from other members of the staff of the University of Minnesota, particularly Prof. W. H. Alderman, Dr. F. K. Butters, and Dr. LeRoy Powers.

by the use of correlation methods, the relationship of the various characters mentioned. Later, several more characters were brought into the correlation studies, and since it seemed logical to infer that the habit of growth in the various organs might be due to the same gene or group of genes, studies were begun to determine the genetic basis of this growth habit as soon as suitable material could be developed.

MATERIALS

In the summer of 1928, a preliminary experiment was carried out in the greenhouse in which 21 varieties and selfed lines of cucumbers were used. These represented a range of mature fruit length of from 360 millimeters in the variety, "Lochie's Perfection," to 170 millimeters in "Snow's Fancy Pickle."

In the summer of 1929, the scope of the experiment was increased and 49 varieties and selfed lines were planted at random in the greenhouse. The mature fruit lengths of these varieties varied from 50 centimeters in "Sutton's Delicacy," an English forcing variety, to 11.7 centimeters in "Chernobrufzy," one of a group of Early Russian importations obtained in 1928 from D. N. Borodin, New York City. The other 47 varieties and strains ranged between the two. In Figure 1 "Sutton's Delicacy" is No. 5 in Group C, and "Chernobrufzy" is No. 5 in Group E.

The summers of 1930 and 1931 were devoted chiefly to the development of material that could be used in the production of an F_2 population for use in further correlation studies and in a study of the inheritance of the previously mentioned growth habit. This consisted of a continuation of the inbreeding of selfed lines, the crossing of types showing extremes of this growth habit, and the selfing of the F_1 progeny obtained from these crosses.

In 1932, an F_2 population, obtained from a cross of an Early Russian selfed line by a selfed line of "Lochie's Perfection," an English forcing variety, was grown in the greenhouse. The English parent had been selfed for five generations and was very uniform in the characters under consideration. The Russian parent had been selfed only two generations and still showed a slight segregation, altho it was rather uniform in the characters involved in this study. Three hundred plants of this F_2 generation were grown, and 20 plants each of the Russian and English parental lines and of the F_1, from which the F_2 population was derived, were systematically distributed among them for comparative purposes.

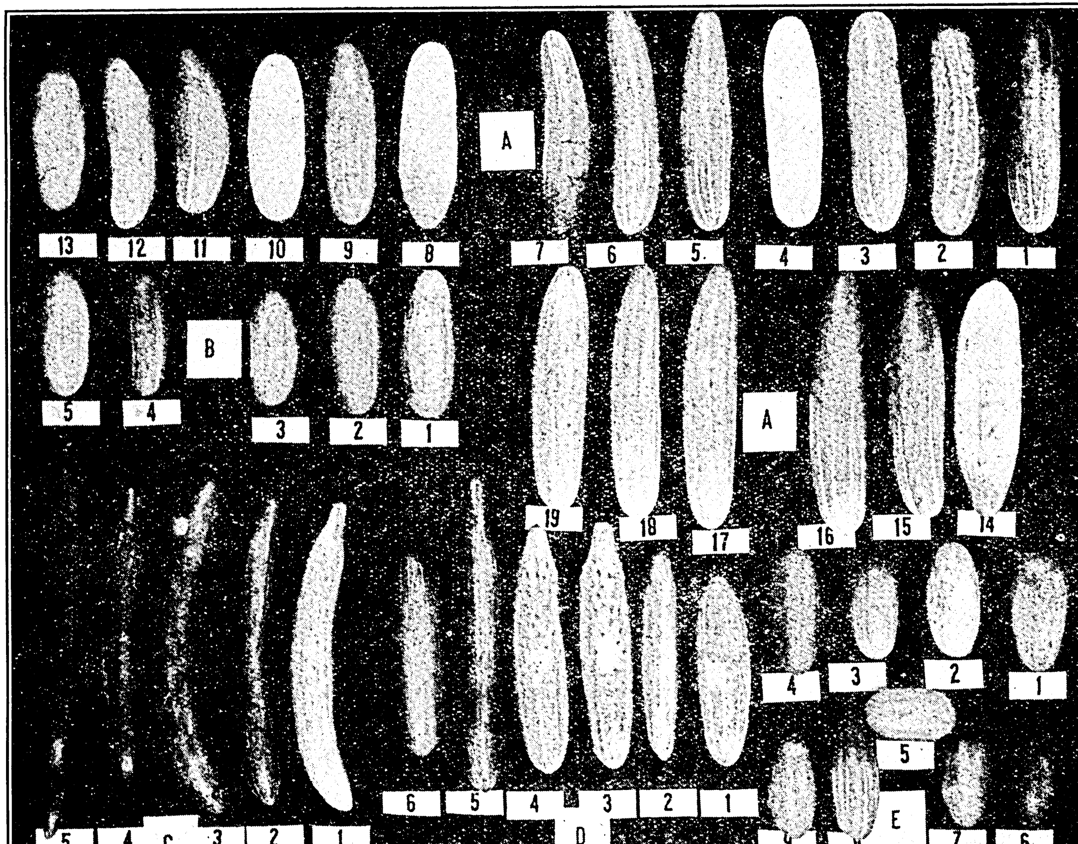

Fig. 1. Typical Mature Fruits of Most of the Cucumber Varieties Grown in the Greenhouse in 1929
(Key on page 6)

Key to Cucumber Varieties and Inbred Lines Illustrated in Figure 1[3]

Group A:
1. Abundance (inbred line)
2. Long Green
3. Danish Pickling
4. New Jap Climbing
5. Abundance (inbred line)
6. Abundance (" ")
7. Abundance (" ")
8. Arlington White Spine (inbred line)
9. Abundance (inbred line)
10. Early Cyclone
11. Kirby's Stay Green
12. Arlington White Spine (inbred line)
13. Klondyke
14. Fordhook Famous
15. Abundance (inbred line)
16. No. 315 American Variety
17. Abundance (inbred line)
18. Abundance (" ")
19. Abundance (" ")

Group B:
1. Boston Pickling (inbred line)
2. Chicago Pickling (" ")
3. Snow's Fancy Pickle (" ")
4. Thorburn's Everbearing
5. Extra Early Green Prolific

Group C:
1. China Long
2. Hunderup
3. Lochie's Perfection (inbred line)
4. Sutton's Improved Telegraph
5. Sutton's Delicacy

Group D:
1. Davis Perfect
2. Sutton's Long Green
3. Davis Telegraph (inbred line)
4. Largin Green (" ")
5. Covent Garden Favorite (inbred line)
6. Fushi-Nari

Group E: (Russian varieties)
1. Imported from Russia
2. " " "
3. " " "
4. " " "
5. " " "
6. " " "
7. " " "
8. Early Russian
9. Imported from Russia

CHARACTERS STUDIED

In the preliminary study in 1928, only four organs—the cotyledons, mature leaves, unfertilized ovaries, and mature fruits, were studied. In 1929, two more organs—the seed and mature internode, were included in the correlations. Nine characters were investigated in the F_2 population grown in 1932. They were the following: Cotyledons, mature leaf, unfertilized ovary, mature fruit, seed, mature internode, height of plant, mature fruit stalk, and mature petiole.

METHODS

Cultural.—Throughout the series of experiments, the seeds were planted in pots and the plants transplanted into greenhouse benches at the proper time and kept under as uniform conditions as

[3] In addition to the above, the varieties Chinese Evergreen, Woodruff's Hybrid, Tottenham, Geneva, and an inbred line of Abundance were included in the test but the fruits did not mature at the proper time to be included in Figure 1.

possible. The usual greenhouse culture for cucumbers was practiced during their development, except that the lateral branches were pinched off slightly beyond the third or fourth node as they developed. This was done to allow the growing of as large populations as possible in the limited space available for the experiments. The method of culture is illustrated in Figure 2, showing a portion of an inbred line of "Lochie's Perfection," grown in the greenhouse in 1931.

Fig. 2. "Lochie's Perfection" Growing in the Greenhouse Bench in 1931

Pollination Practices.—All of the cucumber varieties included in this study were monoecious. Therefore, no emasculation of flowers was necessary in the inbreeding or cross-pollination of the plants. The greenhouse ventilators and doors were completely screened, keeping out the the bees which apparently are the principal insects effecting pollination. To obtain a check on the possibility of chance pollination due to air currents, flies, and smaller insects present in the greenhouse, more than 2,000 flowers were tagged at random, without being pollinated artificially, during the course of the experiments. In no case was a fruit produced which contained seed, altho an occasional parthenocarpic fruit was produced by varieties other than the English forcing types which are normally parthenocarpic. These facts and precautions made bagging and other methods of protecting the flowers against natural pollination unnecessary and greatly simplified the pollination technic. In selfing, a male flower was taken from a plant at anthesis, the petals removed, and the stamens rubbed over the stigma of the female flower on the same plant. In crossing, the same procedure was followed with the exception that the male and female flowers were taken from different plants. Morning pollinations were most effective, altho a fair degree of success was obtained with pollinations made during the afternoon. Throughout the experiments, all fruits studied were artificially pollinated.

Measurements.—In the varietal studies, the mean length and breadth or diameter of cotyledons, mature leaf, unfertilized ovary, mature fruit, seed, and mature internode were obtained for each variety. Twenty measurements of each character were made on each variety, unless otherwise stated, and these measurements were averaged to obtain the mean for the variety. The varietal means were then used to study the relationship between the characters. The number of plants utilized in each variety to obtain the 20 measurements for each character varied with the particular character studied. Measurements of the mature leaves, unfertilized ovaries, mature fruits, and mature internodes were made on four plants of each variety. Five measurements of each character were made on each of the plants except in the case of mature fruit of which it was not always possible to get the full complement of 20 measurements. Cotyledon measurements were taken on 20 plants of each variety. Since there was some variation between the two cotyledons of a plant, both were measured and the average of the two was taken as the length and breadth of cotyledon for the plant. The mean of 20 of these averages was then used as the mean length and breadth of the cotyledon for the variety.

In order to make the measurements of a certain character as comparable as possible in all cases, they were made at a definite time or at a definite stage of growth. The cotyledons were measured when the first true leaf opened. Unfertilized ovary measurements were taken at the time at which the flower opened, and mature fruits were left on the plants until they had fully ripened before they were measured.

In the case of the mature leaves, so definite a criterion could not be established. Here, the measurements were made on the fully developed leaves that were located about half way up the main stem. Internode measurements were made on the third to seventh internodes, inclusive, from the base of the plant, at a time when the leaves borne along these internodes appeared to be fully mature.

In the F_2 population grown in 1932, height of plant, mature leaf petiole, and mature fruit stalk were included in the correlation studies in addition to the characters studied in the varieties. Height of plant was taken when the plants were eight weeks old. At this time a very few plants had produced their first female flower and none their second. Only the length of the fruit stalks of mature fruits and the petioles of mature leaves were taken. The measurements of the other characters were obtained in a manner similar to those taken in the varietal studies, except in the following particulars. Measurements were taken on individual plants and averaged to obtain the mean for the individual. Five measurements of mature leaves, mature leaf petiole, and mature internode, as many measurements as could be obtained of the mature fruits and mature fruit stalks, and from three to twenty-five measurements of unfertilized ovaries were taken per plant and averaged to obtain the mean per plant. The cotyledons of F_3 lines produced by this F_2 and seed from each plant maturing fruit in the F_2 were measured instead of the seed from the F_1 and the cotyledons of the F_2 plants for reasons which will be discussed later. Ten pairs of cotyledons in each F_3 line and 25 seeds from each F_2 plant were measured, the measurements averaged, and the means obtained used in the correlations.

Analytical Methods.—In analyzing the data obtained in 1928, a shape index was used. This index is the same as was used by Salaman (3) in his investigations on the value of a leaf index as an aid in the identification of potato varieties and may be represented by the following formula:

$$\frac{W \times 100}{L} = \text{Index}$$

In the formula, W represents the average width of the organ for the variety and L represents the average length. The width is multiplied by 100 in order to obtain the final result on a percentage basis.

In all the studies made, the relationship of the various characters, as expressed by their mean lengths or indices in the different varieties or in the individual plants of the F_2 population, was studied by the use of correlation surfaces and coefficients. In the varietal experiments conducted in 1929, two sets of these studies were made.

In the first study, the correlations were taken on the indices of the various characters of the different varieties with the exception of the leaves and internodes. In these two cases, no indices were used because of the difficulty in determining a proper method of taking the breadth. Mean lengths were used instead. These indices were first based on the formula as given for the year 1928. However, it was found that this formula gave a negative correlation in comparisons between characters whose measurements were given as indices and those whose measurements were expressed as mean lengths, since the variations of necessity progressed in opposite directions. To cause the variations to progress in the same direction and thus make all the correlations positive, the index obtained in 1928 was subtracted from 100, giving the following formula which proved satisfactory:

$$\text{Index} = 100 - \left(\frac{W \times 100}{L}\right)$$

An analysis of the data, after this set of correlations was partially made, indicated that correlations of the mean lengths of the various characters studied in the different varieties might show the relationship as well as the correlations of the indices. Therefore, a second set of correlations was calculated, in which the mean lengths of the various organs were used instead of their indices.

In the F_2 population grown in 1932 only the mean lengths were correlated.

The correlations were calculated by the machine method by the formula derived by Harris (4). This formula is as follows:

$$r_{xy} = \frac{\frac{\Sigma (XY)}{n} - \overline{X}\overline{Y}}{\sigma X \, \sigma y}$$

PRESENTATION OF DATA

Observational Evidence.—Preliminary observations in the varietal studies indicated that the habit of longitudinal growth, whether long or short, was expressed for each variety throughout the development of the individuals of the variety. For example, long-fruited varieties of the English type of cucumber all had long seeds that gave rise to individuals with relatively long cotyledons, mature leaves, mature internodes, unfertilized ovaries, and mature fruits, while in the short-fruited varieties all these characters were relatively short. Varieties that were intermediate in fruit length were also intermediate in the other characters listed.

It was also found that the average width-to-length ratio of a character gave an index for that character which could be used to show the interrelationship between the various characters of the variety. A long fruit had a smaller index than a short one, and the indices of the various organs of a variety bearing long fruits were relatively smaller than those of a variety bearing shorter fruits.

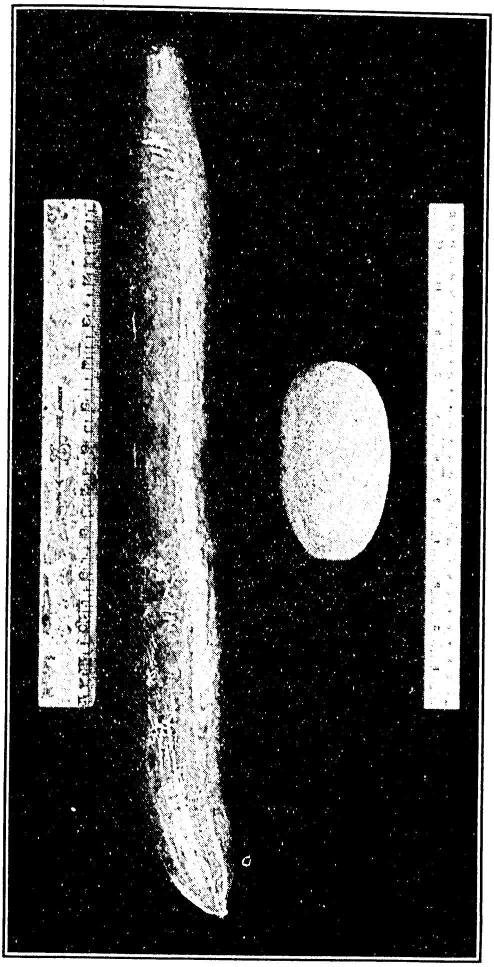

Fig. 3. Typical Mature Fruit of Two Cucumber Varieties Which Differ Greatly in the Length of Their Morphological Characteristics

To clarify the growth relationship in question and to enable the reader to visualize more readily the particular problem involved, Figures 3, 4, 5 and 6 are presented. These figures illustrate typical fruits, unfertilized ovaries, seeds, and cotyledons of two varieties which were the extreme types studied in the varietal experiments in 1929. An English forcing variety, "Sutton's Delicacy," is given as an example of the extreme type which has a very long fruit and a small index. The other extreme is illustrated by a variety of the Early Russian group which has a very short fruit and a relatively large index.

Fig. 4. Unfertilized Ovaries of the Cucumber Varieties Shown in Fig. 3, Russian Variety and Sutton's Delicacy

Figures 3, 4, 5, and 6 illustrate to some extent the growth relationship. Figure 3 shows clearly the difference between the mature fruits of the two extreme types of varieties studied. The English variety has a much longer fruit than the Russian variety and the index of its fruit is much smaller than the index of the other. In Figure 4, the same difference can be noted in the unfertilized ovaries of the two varieties. Figure 5 shows relatively the same difference between the seed of the two varieties. While it is perhaps not so easy to see, close study of Figure 6 will show the same relative difference between the cotyledons.

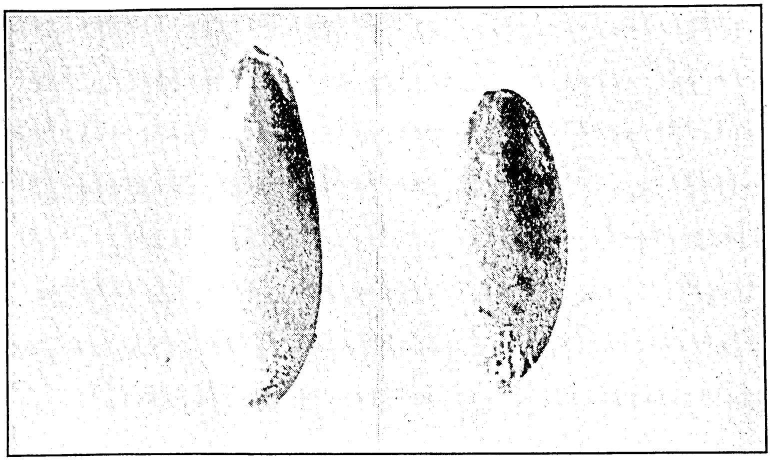

Fig. 5. Seed of the Cucumber Varieties Shown in Fig. 3

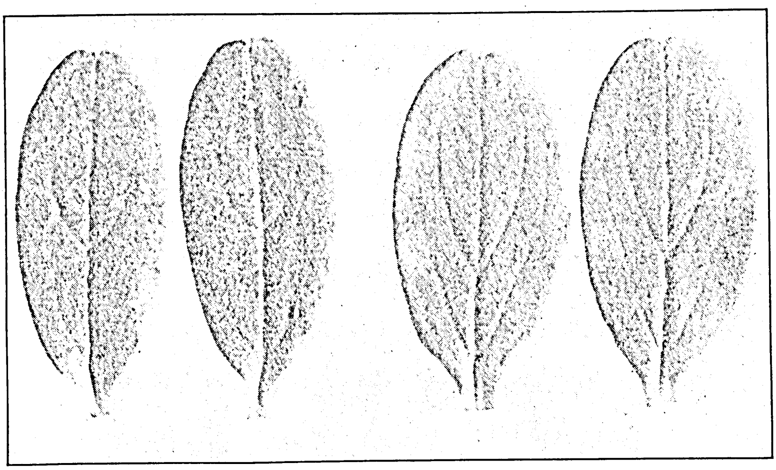

Fig. 6. Cotyledon Pairs of the Cucumber Varieties Shown in Fig. 3, Sutton's Delicacy, left, and Russian Variety, right

As further evidence of the differences between two such varieties, some data obtained in comparisons between parental plants used as checks in an F_2 population grown in 1932 are presented. In this experiment, 20 plants each of "Lochie's Perfection," the English parent which has long fruits, and of "Chernobrufzy,' the Russian parent which produces short fruits, were systematically distributed throughout the F_2 population. The results of comparisons made between these check plants are given in Table 1, in which the mean lengths of the mature leaf, unfertilized ovary, mature fruit, mature internode, height of plant, mature fruit stalk, and mature leaf petiole of the two parents are compared and the difference between the means, probable error of this difference and odds of significance of this difference are calculated.

Table 1 shows clearly the differences between the two varieties in the length of the various characters observed. The odds that these differences are significant are extremely high in all cases except for the height of plant. All the characters of the English variety were consistently longer than those of the Russian variety. In no case was the growth habit of a character so modified as to change the growth relationship in length of the various characters studied.

Table 1

Differences Between the Mean Lengths of Several Characters of Parent Plants Used as Checks in an F_2 Population of Cucumbers Grown in the Greenhouse in 1932*

	Mature leaf	Unfertilized ovary	Mature fruit	Mature internode	Height of plant	Mature fruit stalk	Mature petiole
No. of comparisons	19	16	9	19	19	11	19
Mean length:							
Russian	11.6 ± .4	12.9 ± .2	100.3 ± 5.0	73.4 ± 2.6	38.0 ± 1.6	8.1 ± 0.6	12.2 ± .5
English	16.8 ± .3	46.9 ± .7	408.3 ± 8.3	104.5 ± 2.9	44.5 ± 1.8	43.4 ± 1.9	16.1 ± .4
Difference	5.2 ± .5	34.0 ± .7	307.9 ± 9.7	31.1 ± 3.9	6.5 ± 2.4	35.3 ± 2.0	3.9 ± .6
Odds that difference is significant	Very great	Very great	Very great	Very great	13.6 : 1	Very great	Very great

* Odds obtained by use of Pearl and Miner's Table of Significance of Statistical Constants (5).

For certain characters, in extremes such as are represented by the varieties, some of whose characters are shown in Figures 3 to 6 and in Table 1, the growth relationship involved is self-evident. However, for other characters in these varieties, and for the characters of varieties which are intermediate in fruit length, the relationship is not so obvious and can be demonstrated only by the use of statistical methods:

Experimental Data on Varieties.—In the varietal studies conducted in 1928 and 1929, correlations were made in which the characters studied were intercorrelated in all possible combinations. Table 2 gives a summary of the correlations obtained in the preliminary study conducted in 1928. The correlations were calculated on the shape index of the cotyledon, mature leaf, unfertilized ovary, and mature fruit, and the shape of each of the characters was correlated with the shape of every other character in the series.

Table 2

Summary of Correlation Coefficients Obtained Between the Indices of Several Characters of *Cucumis sativus* in a Study of 21 Varieties in 1928*

Characters correlated	Leaf	Unfertilized ovary	Mature fruit
Cotyledon	0.40 ± 0.12	0.67 ± 0.08	0.63 ± 0.09
Leaf	....	0.51 ± 0.11	0.56 ± 0.10
Unfertilized ovary	....	....	0.97 ± 0.01

* Correlations based on the index, $\frac{W \times 100}{L}$, in which W is the mean width and L the mean length.

The correlations shown in Table 2 are all significant. The lowest, that between the cotyledons and the mature leaf, is 0.40 ± 0.12, and the highest, that between the unfertilized ovary and the mature fruit, is 0.97 ± 0.01. It is interesting to note the extremely high correlation shown in the latter case because it demonstrates clearly that the fruit does not change materially in shape in its development from the unfertilized ovary, or immature stage, to the mature stage. A similar relation between these two characters has been found by workers with certain other crops. Sinnott (6) has shown that the characteristic fruit shape in the squash is maintained throughout the developmental stages from the primordium in the flower bud until it matures. In other words, there is a fairly constant width-to-length relationship throughout fruit development. Yeager (12) states that the size and shape of ripe tomato fruits may be quite accurately determined by an examination of the immature ovary at the time the blossom opens. This relationship between the immature ovary and the mature fruit is not universal in plants, however, since Sinnott (7) states that there is, in many cases, a marked difference between the shape of the mature fruit and that of its primordium in the flower in the peppers.

Since the unfertilized ovary and the mature fruit are so similar in anatomical and morphological characteristics in the cucumber, such a high degree of relationship between them is, perhaps, to be expected. However, one notes from observation very little similarity between the mature fruit and the cotyledon, and yet a correlation of 0.63 ± 0.09 was obtained which indicates a rather high degree of interrelationship. Moreover, the correlations shown in Table 2 indicate a fairly high degree of interrelationship, as far as shape is concerned, between all the characters included in this study. However, the number of varieties studied was small, and it seemed desirable to increase the scope of the experiment to verify or disprove the 1928 results and to test their applicability to a larger proportion of the total population of cucumber varieties. This would permit a more comprehensive study to determine whether this growth relationship between the various organs of a variety was limited to the few varieties studied in 1928, or might be found to exist throughout the whole cucumber species. Investigations were carried on in 1929 in which 49 varieties and strains of cucumbers were used, and two additional characters—the seed and mature internode, were included in the correlations.

Table 3 presents, in the form of a summary of the correlation coefficients obtained, the growth relationship between the cotyledon, mature leaf, unfertilized ovary, mature fruit, seed, and mature internode, each character being correlated with all the other characters. The correlations were all made on a shape index, with the exception of those involving the mature leaf and internode. With these two characters, mean lengths were used.

Table 3

Summary of the Correlation Coefficients Obtained Between the Indices of Several Characters of *Cucumis sativus* in a Study of 49 Varieties in 1929*

Characters correlated	Mature leaf	Unfertilized ovary	Mature fruit	Seed	Internode
Cotyledon	.48 ± .07	.35 ± .08	.32 ± .09	.57 ± .07	.33 ± .09
Mature leaf	....	.52 ± .07	.52 ± .07	.41 ± .08	.39 ± .08
Unfertilized ovary .	....	....	.99 ± .00	.64 ± .06	.55 ± .07
Mature fruit	....	....	....	.65 ± .06	.55 ± .07
Seed	....	....	....	....	.37 ± .09

* Correlations based on the index, $100 - \left(\frac{W \times 100}{L}\right)$, except for the internode and mature leaf in which the measurements used as variables are the average lengths.

The results shown in Table 3 support the data obtained in 1928, as shown in Table 2, and add further proof to the hypothesis that there is a high degree of association between the organs of a cucumber variety in habit of growth. The correlations obtained are all positive and are significant both in relation to their probable errors and according to the criteria of significance of correlation coefficients established by Fisher (8). According to Fisher's criteria of significance, as adapted by Wallace and Snedecor (9), a coefficient of 0.282 is significant, and one of 0.365 is highly significant where 49 observations are made in its computation. Based upon these criteria, the lowest correlation, 0.32 ± 0.09, between the cotyledon and the mature fruit is significant and a majority of the other correlations are highly significant. It is also noteworthy that here again an extremely high correlation, 0.99 ± 0.00, was found between the mature fruit and the unfertilized ovary and that high correlations, 0.65 ± 0.06 and 0.64 ± 0.06 respectively, occur between the shape of these two characters and the seed index. As will be discussed later, there are indications that seed development in the particular growth features involved in this study is delimited to some extent by the growth habit of the mother plant.

While certain of the correlations are fairly low, it is interesting to note that no negative or extremely low correlations were obtained. This tends to prove fairly conclusively that if one of these varieties differs from another in the shape of a particular organ, the mature fruit, for example, it will show the same relative difference in shape of cotyledons, mature leaf, unfertilized ovary, seed, and mature internode. This growth relationship applies not only to the mature characters but persists throughout the growth cycle, as is shown by the interrelationship of the cotyledon and unfertilized ovary with the mature plant characters.

It is also reasonable to suppose that higher correlations might be obtained if more accurate measurements of the growth phenomenon could be taken. Cucumbers are very subject to environmental influences. For example, incomplete pollination, too many mature fruits on a plant, improper fertilizer and moisture applications, too high or low temperatures, variations in the length of day, interference of a tendril, leaf, or stem with the growth of the unfertilized ovary or developing fruit, and insect or other mechanical injury interfere with the normal development of the fruit and may cause it to be abnormal in shape, length, or diameter to some extent. Altho not so noticeable in their effects, some of these factors, and probably others, influence the development of other organs as well and make it difficult to obtain measurements that are accurately descriptive of the growth habit. As previously stated, average measurements were taken for use in determining the correlations, but these were of necessity based on relatively small numbers because of the large number of measurements made, and, while they undoubtedly increased the accuracy, they probably did not eliminate the influence of the environmental conditions entirely. In consideration of these facts and because of observational experience gained through working with the plants, it is believed that the growth relationships between the various organs within the variety are higher than is indicated by the correlations shown in Tables 2 and 3.

During the calculation of the correlations in which indices of the various organs were used as variables, there were indications that correlations based on the mean lengths of the characters studied might show their interrelationship as well as correlations calculated on their indices. A similar correlation series was worked out, therefore, using the mean lengths of the cotyledons, mature leaf, unfertilized ovary, mature fruit, seed, and mature internode as variables. The correlations obtained in this study are shown in Table 4.

Table 4

Summary of the Correlation Coefficients Obtained Between the Mean Lengths of Several Characters of *Cucumis sativus* in a Study of 49 Varieties in 1929

Characters correlated	Mature leaf	Unfertilized ovary	Mature fruit	Seed	Internode
Cotyledon	.46 ± .08	.53 ± .07	.43 ± .08	.52 ± .07	.32 ± .09
Mature leaf	....	.57 ± .07	.58 ± .06	.25 ± .09	.39 ± .08
Unfertilized ovary .	....	....	.87 ± .08	.42 ± .08	.19 ± .09
Mature fruit	....	....	....	.54 ± .07	.52 ± .07
Seed	....	....	....	....	.36 ± .09

The correlations presented in Table 4 indicate that there is a high degree of association within the variety between the mean lengths of most of the characters studied. However, the degree of relationship appears to be less than that obtained between the mean indices, as can be seen by a comparison of the coefficients shown in Tables 3 and 4. This may be due, in part at least, to the fact that length may be affected more than the index by outside influences, and therefore it might be more difficult to get mean lengths that would accurately express the growth habit involved than it would be to obtain mean indices. For example, cotyledons might show a fairly wide variation in length because of environmental conditions or because they were measured at slightly different periods in their development. On the other hand, it is possible and probable that the width-to-length ratio would remain very nearly the same as long as the organ measured was in a healthy and uninjured condition.

The correlation, 0.19 ± 0.09, between the unfertilized ovary and the mature internode is comparatively low, being only slightly more than twice its probable error, and is not significant according to Fisher's criteria. Moreover, nearly all of the correlations in which the mean length of the mature internode is used as one of the variables are low as compared to most of the other coefficients shown in Table 4. A study of the original data indicates that some factor influenced the length of the internode and the length and width of the mature fruit, but did not materially affect the length of the unfertilized ovary or the shape index of the unfertilized ovary or the mature fruit. In studying these data, several varieties were found in which the internodes were much shorter than would be expected on the basis of their unfertilized ovary lengths. It was also noted that most of these discrepancies occurred in a small block of varieties which were more or less infected with mosaic. It is possible that by exerting a stunting effect on the development of the mature fruit and internode mosaic may be a contributing factor in causing this low relationship. The relationship between the shape of the mature fruit and the unfertilized ovary would not necessarily be affected. (See Table 3.) A stunting of the mature fruit on the plants producing the short internodes might account, at least in part, for the fairly high coefficient, 0.52 ± 0.07, obtained between the length of mature fruit and the length of the mature internode. The normal growth habit of the unfertilized ovary, on the other hand, appears to be changed very little, if at all. Therefore, the discrepancies between the length of the unfertilized ovary and the length of the mature internode would be much greater than those between the length of the mature fruit and internode and may account for the much lower coefficient, 0.19 ± 0.09. Additional evidence that this low relationship may be caused by some environmental factor is shown in Table 11, which gives the correlations obtained between the mean lengths of a number of characters of an F_2 population grown in 1932. In this case, a correlation of 0.50 ± 0.03 was obtained between the lengths of the mature fruit and internode, and one of 0.45 ± 0.03 between the lengths of the unfertilized ovary and internode. These coefficients are nearly the same, which is to be expected when two organs showing a fairly high degree of association, as is indicated by the coefficient, 0.72 ± 0.02, are each correlated with a third organ.

The correlation, 0.25 ± 0.09, between the length of mature leaf and seed is also low. As previously stated, a coefficient of 0.282 is considered significant if the number of observations equals 49 (9). This correlation very closely approaches the criterion, and considering also the correlation, 0.41 ± 0.08, between the shape indices of the mature leaf and seed (Table 3), it probably can be considered as a borderline case of possible, altho doubtful, significance.

Taking into consideration all the correlations shown in Table 4, it would seem that, in general, measurements might be taken just as successfully by this method as by the index method but that the investigator would be required to exercise a greater degree of care and exactness in so doing. Certainly the coefficients obtained indicate a fairly high degree of interrelationship between the lengths of the various characters studied. The similarity of results shown in Tables 3 and 4 also suggests the possibility that such measurements might serve as indicators of the shape relationship.

If length could be used as an indicator of the shape relation in these studies, the amount of detailed labor involved could be cut down considerably. Length measurements alone could be taken and the shape predicted from the results obtained by analyzing the length data. This would necessitate, however, that the width of the organs in a variety retain a fairly constant relationship to their length and that this relationship be relatively similar for the various organs of the variety. It would also necessitate that differences between varieties remain fairly constant. In other words, the characters of a variety having longer fruit than another variety should also be relatively wider than those of the second variety. To determine the validity of this idea, correlations were made between the mean lengths and widths or cross-sectional diameters of each of the characters studied in the 49 cucumber varieties investigated in 1929. These correlations are summarized in Table 5.

Table 5

Summary of the Correlations Obtained Between the Length and Width of Several Characters in 49 Cucumber Varieties in 1929 and in an F_2 Population Derived From a Cross, Russian (short fruit) x English (long fruit), Grown in 1932

Characters	Correlation Coefficients: 49 varieties 1929	Correlation Coefficients: F_2 — 1932
Cotyledons	0.75 ± 0.04	....
Mature leaf	0.98 ± 0.00	0.92 ± 0.01
Unfertilized ovary	0.51 ± 0.05	0.31 ± 0.04
Mature fruit	-0.32 ± 0.09	0.55 ± 0.03
Seed	0.40 ± 0.08	0.69 ± 0.02
Internode	0.29 ± 0.09	0.37 ± 0.03

The correlation coefficients shown in Table 5, ranging in the varietal study from 0.29 ± 0.09 in the case of the internode to 0.98 ± 0.00 in the mature leaf, indicate that as the cotyledon, mature leaf, unfertilized ovary, seed, and internode increase in length, as a varietal characteristic, they also increase in width or cross-sectional diameter but probably not proportionately. That is, these characters in a variety having long fruit are not only longer but also wider than in a variety having short fruit. The mature fruit, on the other hand, showed a significant negative correlation, -0.32 ± 0.09, in the varietal study in 1929, which indicates that the converse is true in this case. In other words, as the length of the fruit increases, as a varietal characteristic, its width decreases. It is difficult to understand why this should occur. No explanation has been found, but several tentative theories as to factors which might have some influence in causing this effect might be advanced.

The first is that the fruit actually differs from the other characters studied and does not increase in cross-sectional diameter when it does in length, as an heritable varietal characteristic. In other words, certain varieties may bear mature fruits, which, altho considerably longer, have a smaller cross-sectional diameter than the characteristically shorter fruits produced by other varieties. That this seems to be true in this varietal study can be seen by a careful inspection of the mature fruits shown in Figure 1. In Group C, in particular, the typical mature fruits have very small equatorial diameters as compared to their large polar diameters. The equatorial diameters of some of these fruits are not as large as those of some of the short fruits in Group E. To check this feature further, a similar set of correlations was made on plants grown in an F_2 population of a cross between two inbred cucumber varieties which were homozygous for fruit types showing considerable difference in length, one variety producing very long and the other very short fruit. In this study, mature fruits from 240 plants were measured, and a fairly high degree of association between their widths and lengths noted as is indicated by the coefficient, 0.55 ± 0.03. This suggests that the reason for the negative correlation between the mature fruit width and length obtained in the varietal studies must be sought in another direction, or that some factor disturbs the relationship in the varietal studies which does not influence it or influences it to a less degree in the F_2 population. In this connection, however, it should be stated that the extreme fruit types of the parents possibly were not regained in this F_2 population, altho two plants produced fruits which very closely resembled the English parent, an extremely long type, in length and shape.

Another suggestion is that the fruits of certain of the Russian varieties may be disproportionately wide in comparison to their length. This appeared to be true to some extent in this study. Some of the Russian varieties which fell in the lowest category of length, when a comparison was made on a correlation surface, approached the central category in width.

A third feature, and one which may possibly be the reason for the disturbance of the relationship in the varietal studies, enters into this also. Most of the cucumber varieties studied are pollinated easily and seeds develop throughout their entire fruit length. When complete fertilization occurs and a full complement of seed is matured, the mature fruit usually assumes a somewhat oval shape, the greatest equatorial diameter being near the longitudinal center of the fruit. In these experiments, all the fruits measured were artificially pollinated and the English forcing varieties appeared to be incapable of setting seed throughout their entire length. The seeds were usually confined within a space of four or five inches from the blossom end. On the basis of observations of fruit development in other varieties, it seems logical to assume that fruits from the English varieties would have a much larger equatorial diameter if they could be made to develop a full complement of seed.

In this connection, some observations on Russian varieties furnish additional information. A few parthenocarpic mature fruits have been obtained on such varieties when they were used as the female parent in a cross with *Cucumis melo var. Chito,* the so-called "Garden Lemon." Such fruits developed no seed, but they attained the full length of the normal fruits of the variety. In all cases, however, the equatorial diameter was much less in these fruits than it was in the fruits producing a normal complement of seed. This tends to verify the proposition that the complete development of mature seed is necessary to produce the maximum equatorial diameter which should be characteristic of the fruit of a variety.

While the preceding postulations may offer some indication of the reason for the negative correlation, -0.32 ± 0.09, obtained between the length and width of the mature fruit in the 49 varieties studied in 1929, they do not offer a complete explanation. Such an explanation must be left for future work. However, this correlation necessitated the taking of both shape and length measurements in the F_2 population, which will be discussed next, instead of confining the measurements to length. Because of the high degree of association between the width and length of the various organs in this population, the shape correlations were not calculated.

STUDIES ON AN F_2 POPULATION GROWN IN 1932

Preliminary Discussion

During the progress of the early varietal studies, it was decided to conduct similar investigations on the growth habit of an F_2 population. Accordingly, material suitable for such a study was developed during those years and also in 1930 and 1931. This consisted of the development of inbred lines, their cross-fertilization, and the production and selfing of F_1 populations between inbred lines which produced fruit showing the opposite extremes of fruit length. The study of such a population was undertaken for several reasons.

In 1929, 49 varieties of cucumbers were studied. By growing an F_2 population, the number of individuals, considering each variety as an individual, was increased from 49 to 300, thus extending the scope and value of the experiment by showing the applicability of the growth relationship involved to a larger sample of the infinite population.

It was also desirable to grow such a population merely to give a further check on the results previously obtained, either to prove more conclusively or disprove the hypothesis that there is a high degree of association, within a variety, between the length or the indices of the

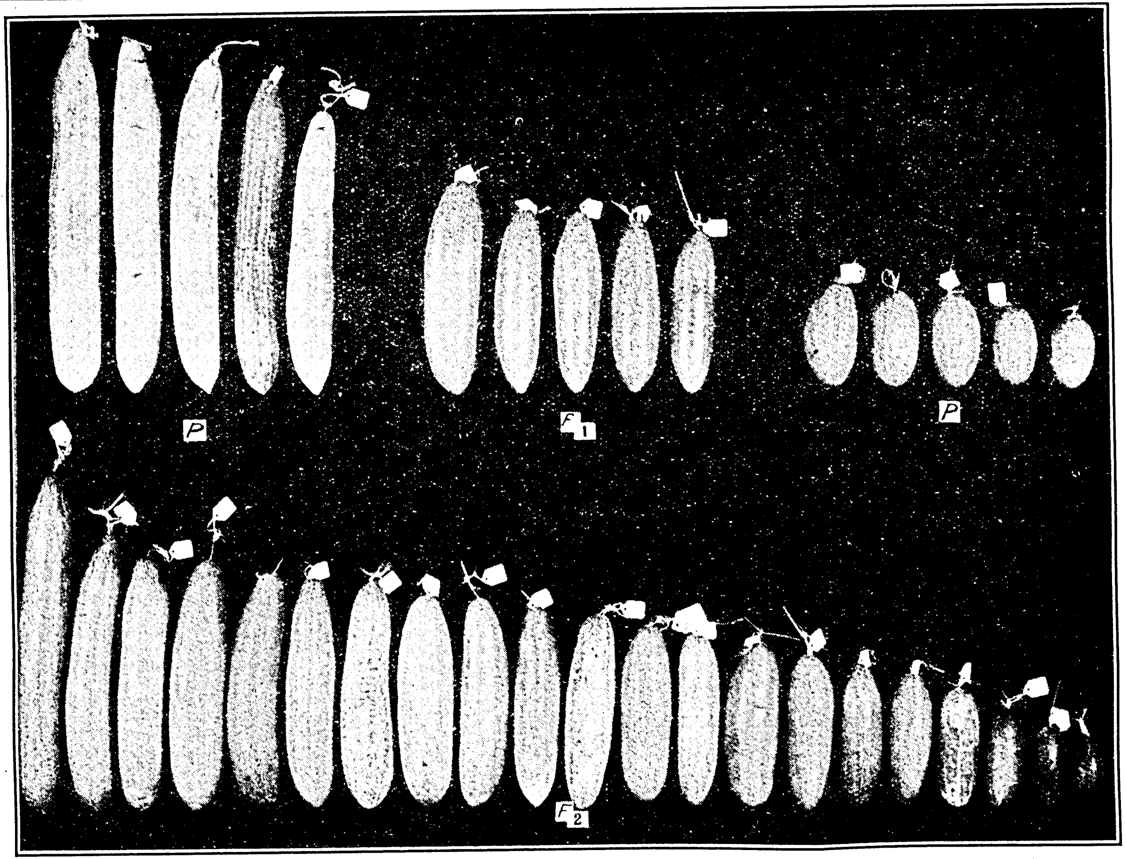

Fig. 7. Cucumbers Grown in the Greenhouse in 1932, Illustrating Typical Matured Fruits of the Parents and of F_1 Progeny and Also a Selected Sample of the F_2 Population Showing the Range of Mature Fruit Lengths Obtained

various organs studied. In addition, it was hoped that such a population would permit the determination of the genetic basis of the inheritance of this growth interrelationship.

Such a population should also give a better distribution of the growth relation, a distribution which would show a more uniform gradation from that of the short-fruited Russian type to that of the long-fruited English forcing type than did the 49-variety sample, certain varieties of which closely resembled each other. That this was obtained is shown to some extent in Figure 7.

In Figure 7, a sample of the mature fruits of this F_2 population is compared with samples of the parental and F_1 populations. Each fruit of the F_2 population is typical of a single plant. In the F_2 population, mature fruits were obtained from 240 plants, only a small number of which are illustrated in this photograph. The group labeled "P" on the left of the picture is representative of the variety "Lochie's Perfection," the male parent, and those with the same label on the right are typical fruits of the Russian variety "Chernobrufzy," the female parent.

Figure 7 shows clearly the intermediate nature of the F_1 and also that a fairly complete range of mature fruit lengths was obtained in the F_2. The mature fruit ranged in length and shape from very nearly the type of the English parent, as illustrated by the F_2 fruit on the left, to nearly the type of the Russian parent, illustrated by the F_2 fruit on the right.

As previously stated, 300 plants of an F_2 population derived from a cross between "Lochie's Perfection," an English forcing variety having very long fruit, and "Chernobrufzy," an early Russian variety having very short fruit, were grown in the greenhouse in 1932. Correlation studies similar to those conducted in the varietal experiments in 1928 and 1929 were made on this population. Before presenting the results obtained in this study, however, certain modifications of and additions to the characters measured previously will be discussed.

Discussion of Certain Characters

Height of Plant.—Some measurement of total plant growth is desirable in a study of this kind. Under the conditions of the experiment it was neither feasible nor practical to take measurements of the entire plant growth or of the mature growth in length of the central axis. However, it seemed plausible to asume that plant growth might be expressed, at least in part, by the height of the plant, or length of central axis, taken at a definite period in the growth cycle. Therefore, the plant height was taken when the plants were 8 weeks old and when only a few of them had produced their first female flower and none their second. To determine the validity of using this measurement in correlations with the other characters studied, correlations were made between plant height, internode length, and number of internodes in the immature (8 weeks old) stage, and between the length of the immature internodes and the length of the mature internodes. In addition, correlations were made between immature height of plant and mature internode length, and between the number and length of the immature internodes. The complete F_2 population of 300 plants was used in this study, and the correlations obtained are presented in Table 6.

Table 6

Relation Between Height of Plant, Length of Internodes, and Number of Internodes at the Immature Stage, and Also Between the Immature Internode Length and the Length of Mature Internodes Taken on an F_2 Population, Early Russian x English Forcing, Grown in the Greenhouse in 1932

Characters	Internode length		No. of immature internodes
	Mature	Immature	
Immature:			
Internode length	.89 ± .01	....	....
Number of internodes	....	.46 ± .03	....
Height of plant	.77 ± .01	.82 ± .01	.80 ± .01

The correlation coefficients presented in Table 6 are all highly significant and show clearly that there is a decided interrelationship between plant height, taken at this time, and the length of immature internodes; between the length of the immature internodes and the length of the mature internodes; and between the height of plant and the length of the mature internodes. This indicates that the height of plant taken at this stage of growth can be used legitimately as an indicator of mature height of plant, altho it is not absolute proof, and this height of plant is used as a variable in the correlations made on the F_2 population.

In addition, Table 6 also brings out another interesting relationship. The correlation, 0.82 ± 0.01, between the height of plant and the immature internode length is practically identical with the correlation, 0.80 ± 0.01, obtained between the height of plant and the number of immature internodes. In other words, plants having comparatively long characteristics not only have longer internodes but also a larger number of internodes than those having shorter characteristics. This may indicate that the former plants have a relatively more rapid rate of growth, at least in length, than the characteristically shorter plants.

However, it is not known whether this growth habit would hold in the mature plant or in other characters besides the internode, and further studies are desirable to determine this and to discover an explanation of this phenomenon.

Seed and Cotyledons.—In preliminary studies made on F_1 and F_2 populations in 1930 and 1931, it was noted that the seed produced in a cross or by an F_1 plant approached the female parent in length and index. Moreover, the influence of the female parent appeared to extend into the cotyledons of the F_1 and F_2 plants as well. This phenomenon is illustrated in Tables 7 and 8.

Table 7

A Comparison of the Mean Seed Measurements of Russian (short) and English (long) Cucumbers in 1931, With F_0 Seed Produced by Reciprocal Crosses Between Them and With F_1 Seed Produced by the F_1 Plants of These Crosses

	Average length in cm.	Index $\frac{W \times 100}{L}$	Number of measurements
Parents:			
English	1.13 ± 0.005	38.05	118
Russian	.90 ± 0.002	44.38	525
Mean of parents	1.02	41.215	...
F_0 seed:*			
English x Russian	1.11 ± 0.003	39.63	141
Russian x English	.88 ± 0.002	44.94	324
F_1 seed:†			
English x Russian	1.08 ± 0.002	40.74	375
Russian x English	.94 ± 0.002	43.62	573

* F_0 seed obtained from fruit produced by cross-fertilization.
† F_1 seed obtained from F_1 plants.

Table 8

A Comparison of the Mean Cotyledon Measurements of Russian (short) and English (long) Cucumbers, in 1931, With Those of F_1 and F_2 Populations Derived from Reciprocal Crosses Between Them

	Average length in cm.	Index $\frac{W \times 100}{L}$	Number of measurements
Parent:			
English	5.70	45.13	4
Russian	4.71 ± 0.12	54.51	31
Mean of parents	5.21	49.82	..
F_1:			
English x Russian	5.62 ± 0.18	45.44	22
Russian x English	4.68 ± 0.10	50.96	47
F_2:			
English x Russian	5.29 ± 0.08	46.64	72
Russian x English	4.58 ± 0.05	52.62	165

Tables 7 and 8 show rather clearly that the mean lengths and indices of seed produced in a cross or by the F_1 plants, and of the cotyledons of F_1 and F_2 plants produced from such seed, approach the length and index of the female parent no matter which parent is used as the female. Since the seed coat is part of the female plant, it can be explained why the seed should show this reaction by postulating that the seed coat limits the growth of the embryonic plant while it still encloses it. The data obtained on the cotyledons of the F_1 and F_2 plants are not so easily explained, and no work has been done as yet to determine the reason for this interesting phenomenon.

A similar study was made on the seed and cotyledons of the parents, F_1 and F_2, grown in the greenhouse in 1932 and discussed in this paper. No reciprocal crosses were made. The data, however, provide a partial check on the previous results. These data are presented in Tables 9 and 10.

Table 9

A Comparison of the Mean Seed Measurements of Russian (short) and English (long) Cucumbers, in 1932, With F_0 Seed Produced by a Cross, Russian x English, and With F_1 Seed Produced by the F_1 Plants of This Cross

	Average length in cm.	Index $\frac{W \times 100}{L}$	Number of measurements
Parent:			
Russian	.99	46.46	108
English	1.03	41.74	179
Mean of parents	1.01	44.10	...
F_0 Seed:			
Russian x English	.91	50.55	102
F_1 Seed:			
Russian x English	.91	48.35	328

Table 10

A Comparison of the Mean Cotyledon Measurements of Russian (short) and English (long) Cucumbers, in 1932, With Those of F_1 and F_2 Populations Derived From a Cross Between Them

	Average length in cm.	Index $\frac{W \times 100}{L}$	Number of measurements
Parent:			
Russian	4.07	58.97	34
English	5.02	47.01	34
Mean of parents	4.545	52.99	..
F_1:			
Russian x English	3.97	52.14	30
F_2:			
Russian x English	4.29	54.08	328

Altho the relationship is not so pronounced, the data presented in Tables 9 and 10 show a trend similar to those obtained in 1931, with one exception. That is, the mean index of the F_1 cotyledons closely approaches the mean of the two parents, which normally would be expected. This variation, however, may be due to the fact that the seeds in this case were not plump and well developed and that the plants derived from them were weak and slow to develop.

Assuming that Tables 7 to 10, inclusive, accurately represent a growth phenomenon which occurs in cucumbers, a modification of the method of taking the measurements of the seed and cotyledons of the F_2 population is necessary to obtain results illustrative of the true growth relationship. This is particularly true of the seed where, due to the influence of the female parent, the seeds obtained from an F_1 plant resemble in length and shape the F_1 plant from which they were obtained rather than the F_2 plants which they produce. Therefore, the seeds used in the F_2 correlation studies were obtained from the F_2 plants and the cotyledons from the means of F_3 lines derived from such F_2 plants. Ten pairs of cotyledons from each F_3 line and 25 seeds from each F_2 plant were measured, the measurements averaged, and the means obtained used in calculating the correlations. The results of this study are summarized in Table 11, in which the coefficients obtained by intercorrelating, in all possible combinations of pairs of characters, the lengths of the cotyledons, mature leaf, unfertilized ovary, mature fruit, seed, mature internode, height of plant, fruit stalk, and mature petiole are given.

The correlation coefficients shown in Table 11 indicate that the growth relationship is expressed in this F_2 population in the same manner as in the varietal studies. The coefficients are all positive and significant according to the criteria of significance of "r" as adapted by Wallace and Snedecor from tables compiled by Fisher. The smallest number of observations correlated in this study was 236, between the unfertilized ovary and the mature fruit. The largest was 300. According to Fisher's criteria (9), a coefficient of 0.130 is signicant and one of 0.170 is highly significant for a correlation based on 236 observations. The lowest correlation was 0.14 ± 0.04 between the length of the seed and the height of plant, and the highest 0.77 ± 0.02 between the height of plant and the mature internode. It is also interesting to note the high correlation, 0.62 ± 0.03, between the length of mature fruits and the length of seeds obtained from these fruits. This tends to justify the use of seed from F_2 fruits to express the growth relationship that exists between the seed and other cucumber organs.

Table 11

A Summary of the Correlations Obtained, in 1932, Between the Mean Lengths of Several Characters in the F_2 Progeny of a Cucumber Cross, Russian (short) x English (long)

Characters	Mature leaf	Unfertilized ovary	Mature fruit	Seed (from F_2 plants)	Internode	Height of plant	Mature fruit stalk	Mature petiole
Cotyledons (F_3 plants)	.41 $\pm$ .03	.39 $\pm$ .04	.52 $\pm$ .03	.65 $\pm$ .02	.47 $\pm$ .03	.31 $\pm$ .04	.34 $\pm$ .04	.27 $\pm$ .04
Mature leaf	....	.42 $\pm$ .03	.47 $\pm$ .03	.38 $\pm$ .04	.69 $\pm$ .02	.60 $\pm$ .02	.26 $\pm$ .04	.56 $\pm$ .03
Unfertilized ovary	....	....	.72 $\pm$ .02	.43 $\pm$ .03	.45 $\pm$ .03	.31 $\pm$ .04	.22 $\pm$ .04	.30 $\pm$ .04
Mature fruit	....	....	....	.62 $\pm$ .03	.50 $\pm$ .03	.34 $\pm$ .04	.33 $\pm$ .04	.40 $\pm$ .03
Seed (from F_2 plants)	....	....	....	....	.30 $\pm$ .04	.14 $\pm$ .04	.39 $\pm$ .04	.31 $\pm$ .04
Internode	....	....	....	....	....	.77 $\pm$ .02	.20 $\pm$ .04	.42 $\pm$ .03
Height of plant	....	....	....	....	....	....	.15 $\pm$ .04	.34 $\pm$ .03
Mature fruit stalk	....	....	....	....	....	....	....	.41 $\pm$ .04

While a number of the coefficients are so small as to indicate a fairly low, altho still significant, degree of association between certain of the characters studied, the trend is in all cases similar, no combinations showing no correlation or a negative relationship. In other words, a plant producing a long fruit also has long cotyledons, mature leaves, unfertilized ovaries, seeds, mature internodes, central axis, mature fruit stalks, and mature petioles.

DISCUSSION

This study, while primarily of interest in showing the interrelationship in shape and in length of a number of morphological characters of the cultivated cucumber, is also of interest from the standpoint of heredity, varietal classification and identification and its application to cucumber breeding. These features will be discussed under the headings of morphological development, inheritance, and practical application.

Morphological Development

The preceding data have shown a very definite association between the various organs of the cucumber plant in length and probably in shape. This association is shown not only by the mature plant characters but is demonstrated in the young plant as well. The fact that differences in the longitudinal growth of varieties and of individual plants in an heterogeneous population can be demonstrated in the unfertilized ovaries and cotyledons suggests that differentiation occurs at an early stage in the development of the plant and may possibly be traced to differences in the growth of the individual cell, either as size differences or differences in the rate of multiplication or division in a certain plane. Some studies (10), which have not been reported, indicate that certain of the cells, at least, vary in length and shape in the same manner as the previously named morphological characters of the parent plant. For example, there are indications that sieve tubes and pollen grains have smaller indices and greater lengths in the English than in the Russian cucumber varieties. However, superficial attempts to find a like relation in other cells or tissues have not been successful, and it has not been determined, as yet, whether the length and shape relationship found between the morphological characters studied is present in the anatomical characteristics as well. Nor are the meager data obtained on sieve tubes and pollen grains conclusive enough to warrant the assumption that such a relation may exist, but merely suggest that some cells, at least, would show a certain degree of positive association with length and shape of the morphological characters studied.

It is also of interest to note that varietal differences in the length and shape of at least several of the morphological characters studied are readily demonstrated at a very young stage in their development and remain relatively constant throughout growth to the mature stage. This is particularly noticeable in fruit development, as illustrated in Figures 3 and 4 and also by the highly significant correlations obtained between the length and shape of the unfertilized ovary and the same characters of the mature fruit. This is so apparent in varieties showing the opposite extremes of fruit length that relative differences in length of the mature fruits can be predicted fairly accurately from the relative differences existing in the unfertilized ovaries as soon as the ovary is discernible to the eye. This is in agreement with the studies of Sinnot and Durham (6) who found differences in the fruit shape in certain varieties of *Cucurbita pepo* could be detected in the primordium of the female flower and that shape measurements taken at this stage of growth gave an accurate portrayal of the shape of the mature fruit.

Another interesting morphological relationship suggested by the data is that of the influence which appears to be exerted by the mother plant on the seeds produced by it and on the cotyledons of plants produced from these seeds. Since the seed coat is a part of the mother plant, it is reasonable that the F_0 seed and perhaps the F_1 cotyledons should resemble the mother plant. However, the data show that this influence is also exerted to some extent on the F_1 seed and F_2 cotyledons. In general, the F_1 progeny of reciprocal crosses of this type should resemble each other. These two characters, however, do not follow the general rule but resemble the female parent no matter which way the cross is made. It is not known whether other characters show this feature. The data from which these results were obtained were not devised as a test of this relationship and did not permit the study to be carried further. Other studies are being carried on at present with the object of testing this phenomenon, and it is hoped that more conclusive results may be obtained.

Inheritance

Interrelationships between the morphological characters of the cucumber, such as have been shown in this study, are of interest from the standpoint of heredity. The fact that varieties having long fruit also are longer in respect to all the other characters studied indicates that the length, and perhaps the shape, of all these organs are due to the same gene or group of genes. Data obtained from a study of fruit length and shape in F_2 and F_3 generations suggest that at least three genes are involved. These genes appear to determine the method of growth which in the course of development can be noted in the cotyledons, mature leaf, unfertilized ovary, mature fruit, seed, mature internode, height of plant, mature fruit stalk, and mature petiole. In other words, the effect of the genes is not specific for any given organ but is general, covering the growth of the entire plant. The relationship is more evident in some plant organs than in others. The measurements probably do not express the underlying growth habit with equal accuracy for the different organs, but all the plant parts under observation show a similar response in the same individual from the seedling to the mature plant, irrespective of its genetic constitution. The genes determine the particular method of growth for the plant as a whole.

Data have been secured on the inheritance of the genes as they affect the mature fruit and certain other characters in F_1, F_2, and F_3 generations. These data will be published later, when completely analyzed. Observations of these populations, however, indicate that at least three genes are involved in the inheritance of the length or shape of the cucumber fruit and that there is no linkage, or at most a very weak linkage, between them. A normal distribution occurs, as is illustrated to a certain extent in Figure 7. The correlations shown in Table 11 also show this to a certain degree, and further observations on a larger F_2 population grown in the field in 1933 show that there are no departures and that all the characters studied are inherited in a similar manner. In other words, if one of the segregates produces a fruit of intermediate type, the other organs of this segregate are also intermediate in type.

Possibly not only width and length dimensional factors are involved, but also a regulating factor which controls the relation of length to width; in other words, a shape factor. This is indicated by the correlations shown in Table 5 which demonstrated that, in all the characters studied except the mature fruit, the width of the organs increased as their length increased. It is hoped that this point may be determined more conclusively in studies being carried on at the present time.

Some Practical Applications

While this study is primarily of interest in showing the interdependence existing between the various organs of the cucumber, it may also be of value from the standpoint of varietal classification and identification and in future plant breeding and genetic studies.

Salaman (3) has emphasized the usefulness of a "leaf index," such as was used in some of these studies, in furnishing evidence as to the identity of suspected synonymous stocks of potatoes growing in the trial plots of the National Institute of Botany. Krantz and Hutchins

(11) have shown that the value of such an index for this purpose may be influenced considerably by environmental conditions, but state that in varieties grown under comparable conditions it may be a valuable addition to other characters which are utilized for the identification of varieties and the detection of synonyms. The data obtained in these experiments indicate a rather constant difference between varieties in the length and, in some cases, the shape of the various organs studied. If such is the case, a study of the length and shape of these organs in disputed cucumber varieties should provide a definite and valuable addition to the characters utilized in the determination of their synonymity and identification.

Such information as has been shown herein should also be of value in breeding work and genetic studies with cucumbers. For example, if a particular shape or length of fruit is desired, the labor involved in breeding for such a type could be cut down considerably in the F_2 population since, knowing the high degree of length and shape association between the unfertilized ovary and the mature fruit, seedlings could be selected or discarded on the basis of the length and shape of the unfertilized ovary. In this region, it is also difficult to obtain self- or cross-pollinated fruits from plants selected in the field if one has to wait until fruit matures on the plant in order to determine whether the plant bears the desired fruit type or not before selections for selfing or crossing purposes can be made. Knowing the high degree of positive association in length and shape between certain seedling characters and certain characters of the mature plant might allow one to select for these mature characters on the basis of the seedling characteristics, thus increasing the probability of getting mature fruit from self- or cross-pollinated selections.

SUMMARY

In 1928, 1929, and 1932, studies were undertaken to determine the degree of association in length and in shape of a number of organs of the cultivated cucumber, *Cucumis sativus L.* In these experiments, 21 varieties and inbred strains were utilized in 1928, 49 varieties and inbred strains in 1929, and an F_2 population of 300 individuals in 1932. This F_2 population was derived from a cross between two inbred lines which produced mature fruit of different mean lengths, one bearing very long and the other very short fruit.

All studies were conducted under controlled conditions in the greenhouse. Correlation studies were made on variables which were based on the average lengths or indices of the characters investigated. The length and sometimes the shape of each character studied was correlated with the length and shape of every other character analyzed in the particular experiment.

In these experiments, it was found that: (1) The cotyledons, mature leaf, unfertilized ovary, mature fruit, seed, mature internode, height of plant, mature fruit stalk, and mature petiole showed a high degree of association with each other in length and shape, both within the variety and within an heterogeneous group as represented by the F_2 population. (2) This growth relationship is expressed not only in the mature morphological characters but is present throughout growth from the seedling to the mature plant and may possibly be demonstrated to occur in certain of the individual cells. (3) The gene or genes influencing this relationship are not specific for a given organ but affect all the organs studied in a similar manner. In other words, these genes determine the method of growth, in this particular, for the plant as a whole.

The data, experimental and observational, indicate: (1) That at least three genes are involved in the inheritance of this growth relationship and these genes are not linked. (2) The possibility that the genes involved are not dimensional factors for length and width of the various organs but are shape factors regulating the relation of width to length. (3) That the length and shape of the seed and cotyledons are influenced to a greater degree by the female than by the male parent. (4) That the rate of growth may be more rapid in the plants producing long organs than in those producing relatively shorter ones.

The fact that there is a fairly constant difference between cucumber varieties in length and shape of the characters studied adds to the knowledge which may be utilized in the classification and identification of varieties.

A knowledge of the high degree of association which was found between certain seedling and mature plant characters may be of value in genetic and plant breeding studies in permitting selection for mature characters on the basis of seedling characters and in permitting selection and the production of seed by the self- or cross-pollination of such selections in the field.

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